Early LHC: What Do I Expect?

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1. Physics at the Electroweak Scale: Why LHC?

2. Early LHC: What Do I Expect?

3. Summary

Origin of electroweak symmetry breaking

$\Leftrightarrow$ What is the origin of the masses of SM particles

Usually, Higgs mechanism is adopted:

$$V = \frac{1}{4}\lambda(|H|^2 - v^2)^2 \quad \text{with } v \simeq 174 \text{ GeV}$$

$$\Rightarrow H^0 = v + \frac{1}{\sqrt{2}}h \quad \text{with } m_h = \sqrt{\lambda} v$$

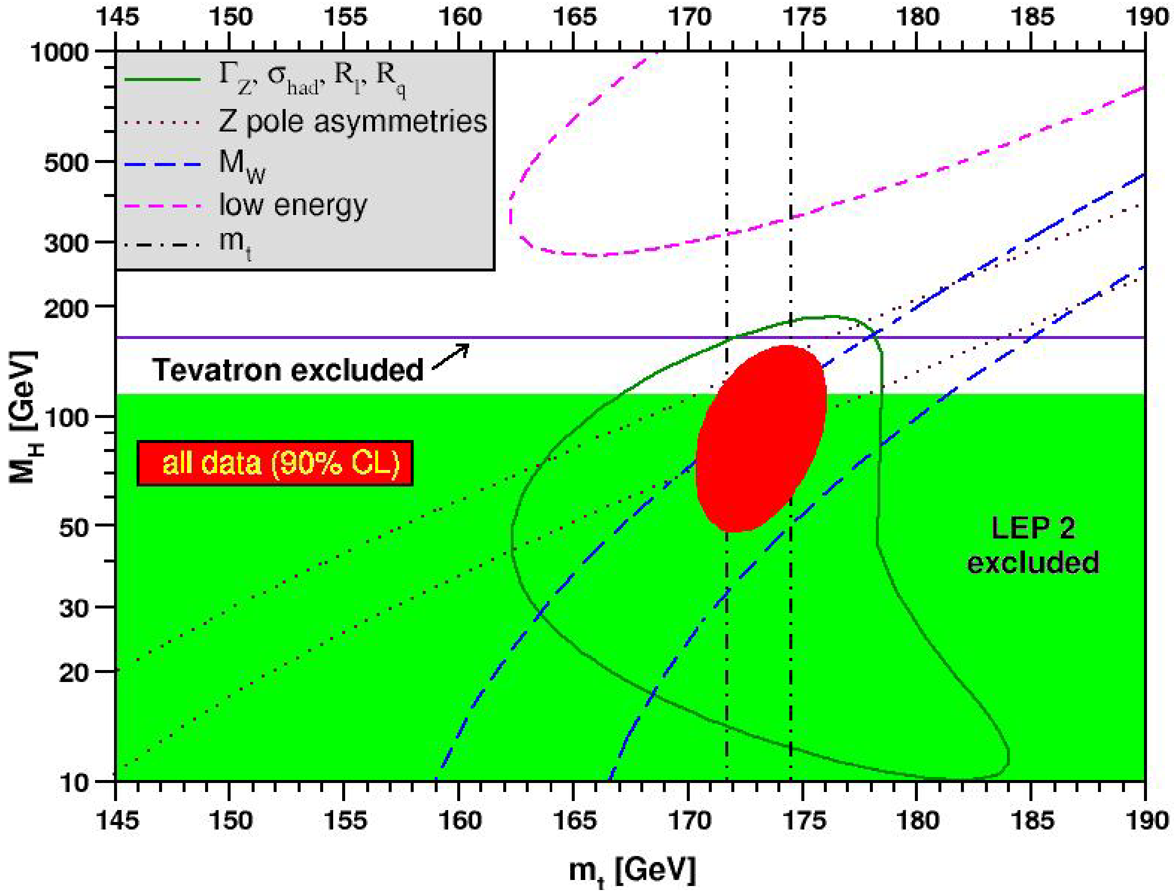
$\Rightarrow m_h$: Free parameter in the SM

Discovery of SM Higgs boson is guaranteed at the LHC

$\Leftrightarrow$ For non-SM case, cross your fingers...

$\Leftrightarrow$ Or in some model, there is no Higgs particle...

Constraints on m_t vs. m_h plane: precision data



[Erler (2010)]

$\Rightarrow m_h \leq 148$ GeV (90 % C.L.)

Discovery of new physics

$\Leftrightarrow$ Need (or want) some mechanism to stabilize EW scale

Stabilization by symmetry between boson and fermion

$\Rightarrow$ SUSY

Low-energy cutoff of order ~ 1 TeV

$\Rightarrow$ UED, RS, $\cdots$

Stabilization by gauge symmetry

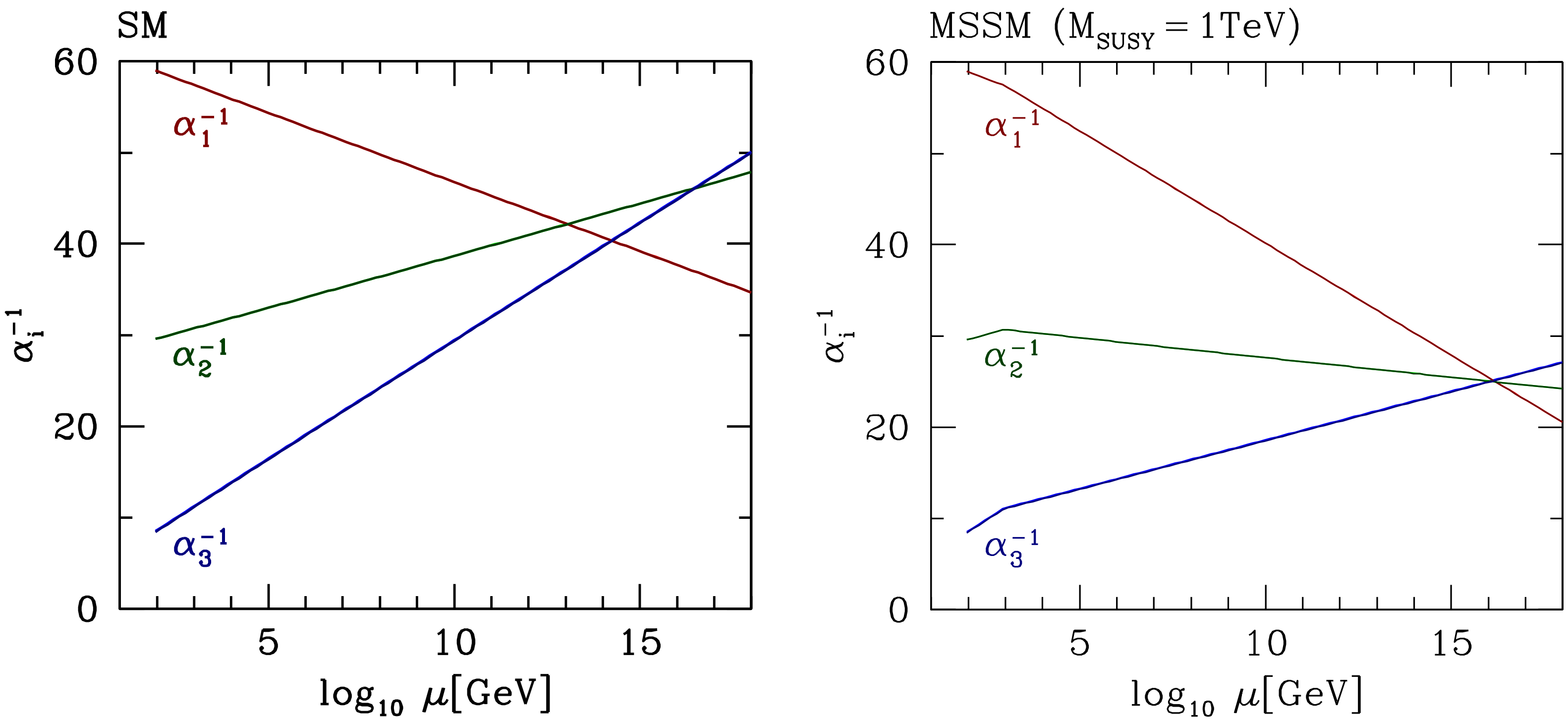
$\Rightarrow$ Gauge-Higgs unification

Higgs as a Nambu-Goldstone boson

$\Rightarrow$ Little-Higgs, $\cdots$

Gauge coupling unification in supersymmetric model

$\Rightarrow$ Another support of low-energy SUSY

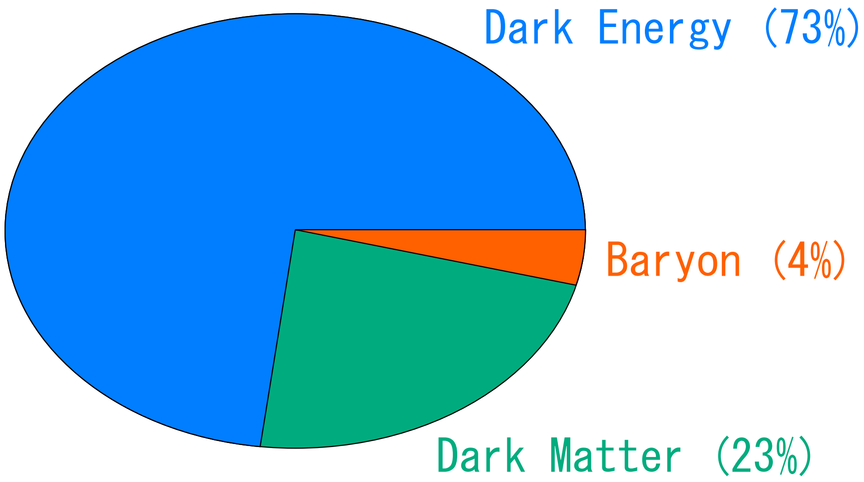


Other check points of SUSY GUT:

$\Rightarrow$ Gaugino mass unification, Sfermion mass unification, $\cdots$

Dark matter

⇔ Dark matter exists, but we don't know what it is



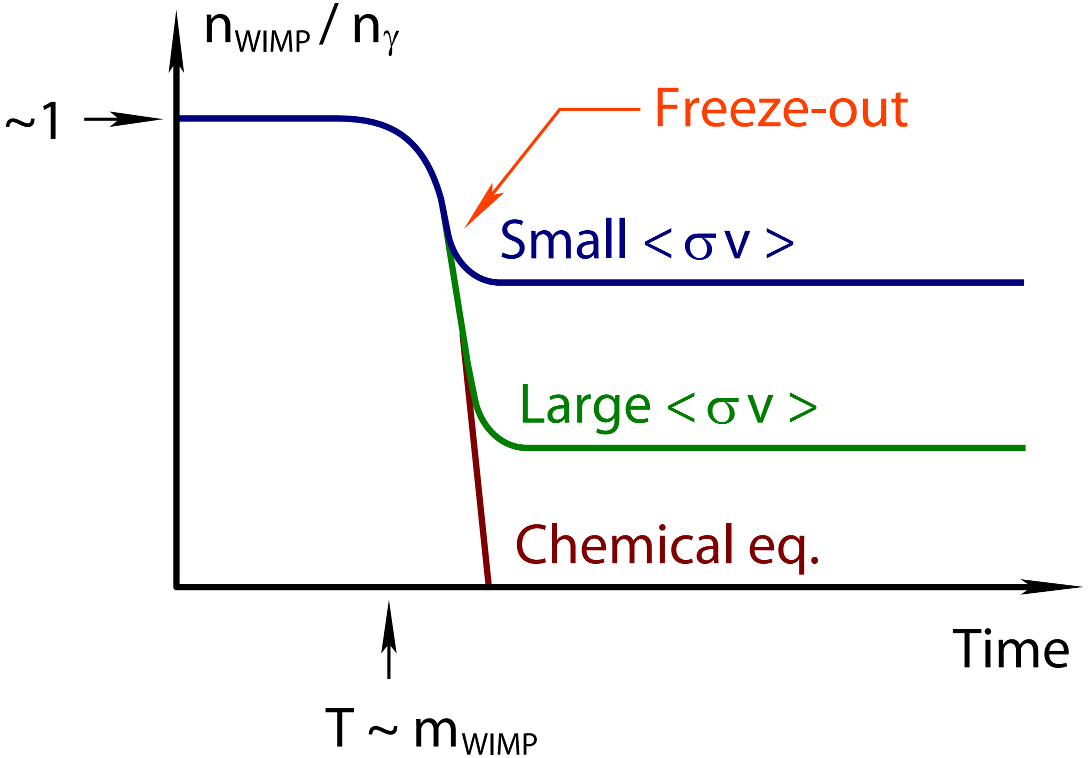
What is dark matter?

⇒ Particle or something else?

⇒ Production mechanism?

One possibility: thermal relic WIMP dark matter

WIMP: weakly interacting massive particle



$$\Rightarrow \quad \Omega_{\text{WIMP}} \simeq 0.2 \times \left(\frac{\langle \sigma v \rangle}{0.9 \text{ pb}} \right)^{-1}$$

Notice: $0.9 \text{ pb} \sim \dfrac{4\pi\alpha^2}{(500 \text{ GeV})^2}$

Candidates of WIMP dark matter

- The lightest neutralino (SUSY)
- KK $U(1)_Y$ gauge boson (UED)
- T-odd gauge boson (Little Higgs)
- $\cdots$

They may be produced at the LHC

$\Rightarrow$ Properties of the WIMP may be determined

$\Rightarrow$ Study of the early universe may be possible

$\Rightarrow$ Thermal history back to $T \sim O(10\ \text{GeV})$ may be understood

Motivations to study physics at the EW scale

- (Light) Higgs boson
- Stability of the EW scale against radiative correction
- Dark matter
- Physics beyond the standard model
- $\cdots$

LHC (14 TeV run) will give us a clue to attack these issues

$\Rightarrow$ How about the "early LHC"?

(Early LHC: $\sqrt{s} = 7$ TeV & $\mathcal{L} \sim 1$ fb^{-1})

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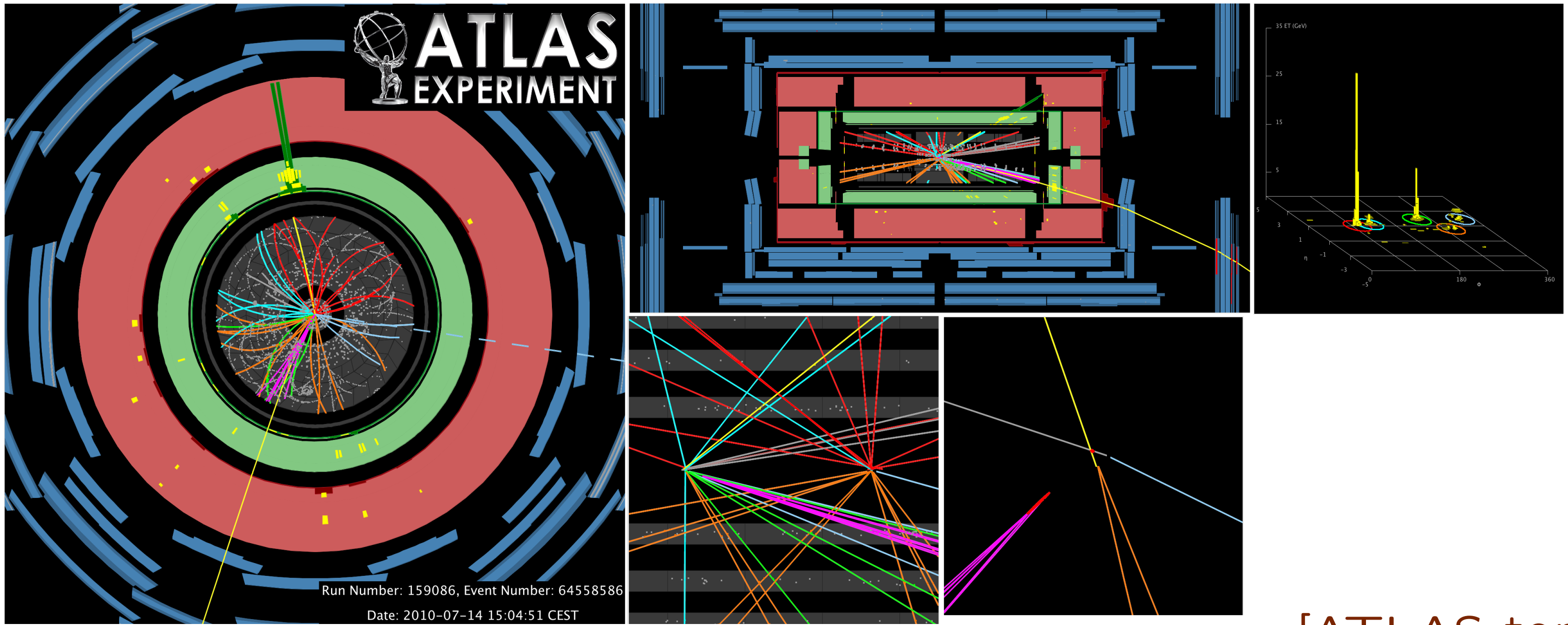
Re-discovery of the standard-model particles

- Weak bosons: there are already candidates
- Top quark: there are already candidates

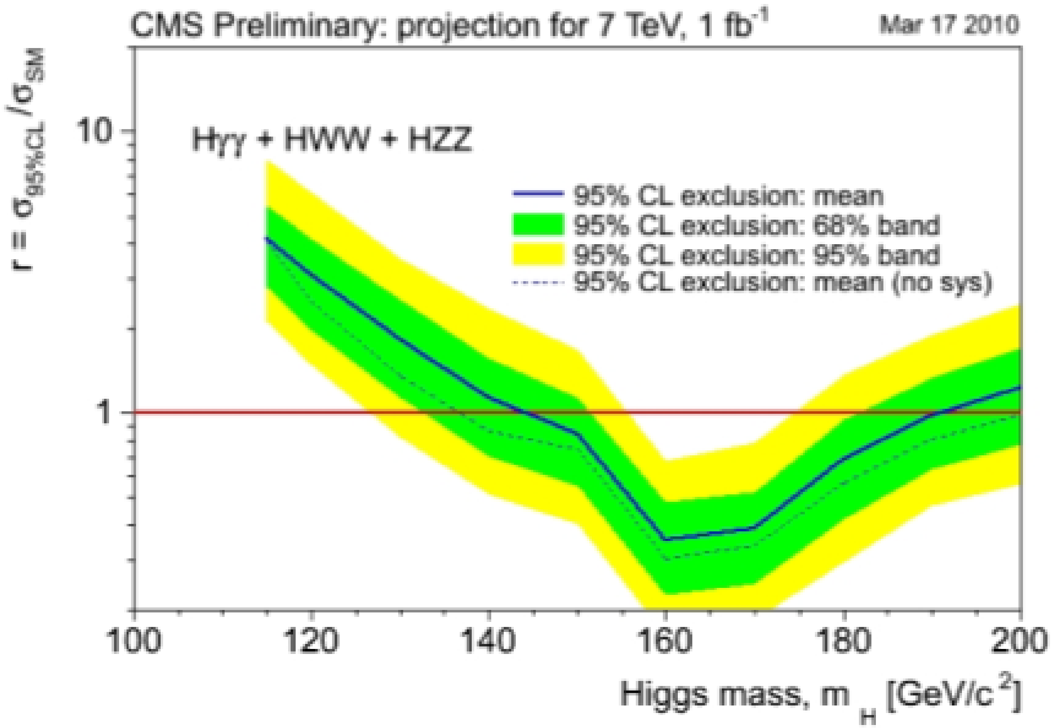


[ATLAS top event]

⇒ We will be confident that the detectors are working well

⇒ SM events are used for calibration

Higgs



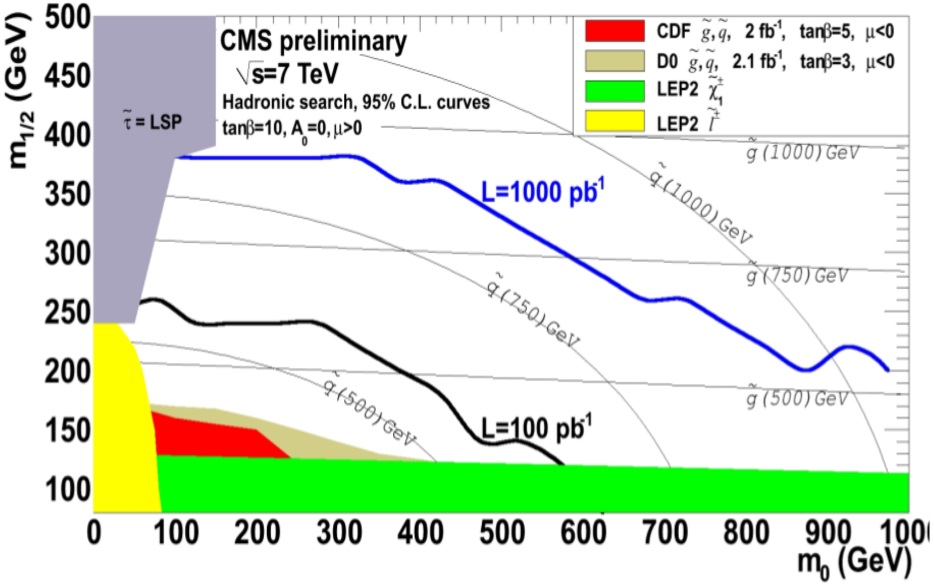
[CMS note]

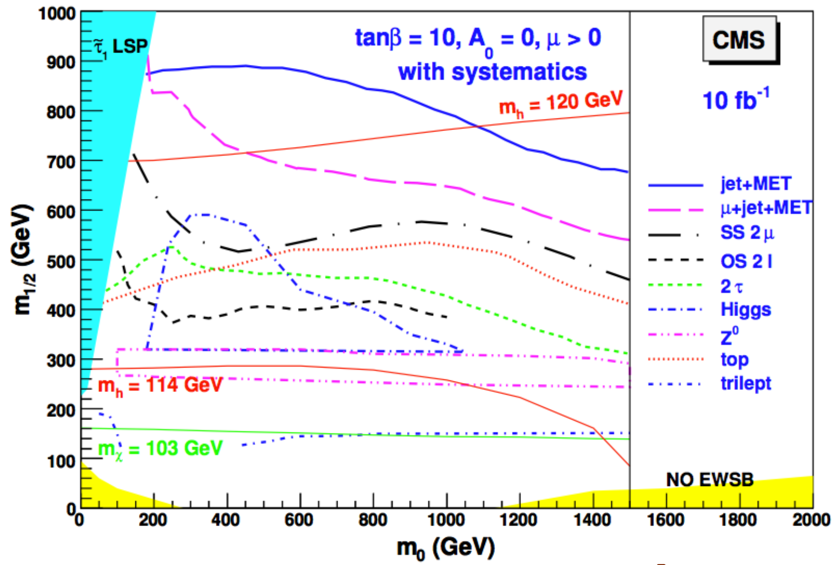
$\Rightarrow m_H \sim 140 - 190$ GeV can be excluded

$\Rightarrow 5\text{-}\sigma$ discovery is not expected

$\Rightarrow$ If SUSY (i.e., $m_H \lesssim 120$ GeV), for e.g., we should wait the 14 TeV run (with $\mathcal{L} \sim 10$ fb^{-1}) for discovery

SUSY





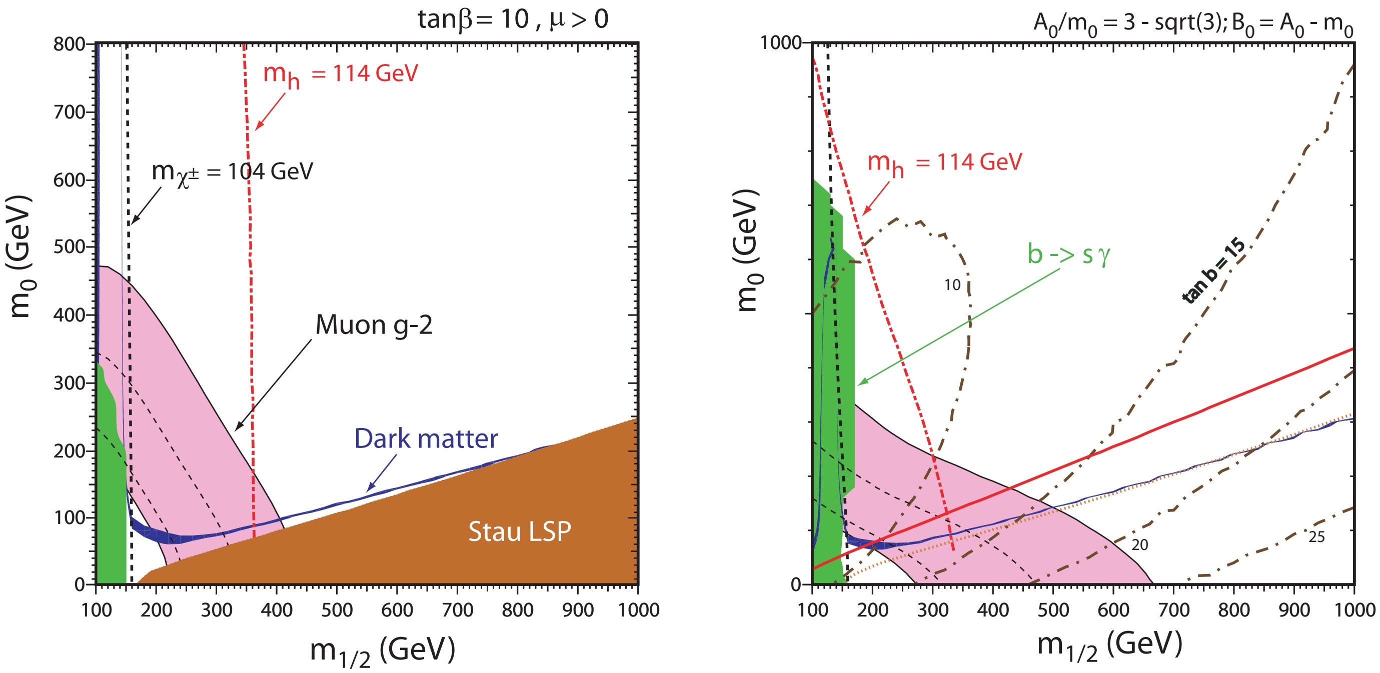
[CMS note]

$\Rightarrow$ Discovery reach: $m_{\tilde{q}} \lesssim 800$ GeV or $m_{\tilde{g}} \lesssim 600$ GeV with 7 TeV

Exotic signals may exist in some class of SUSY models

$\Rightarrow$ See the discussion below

Other constraints (on CMSSM)



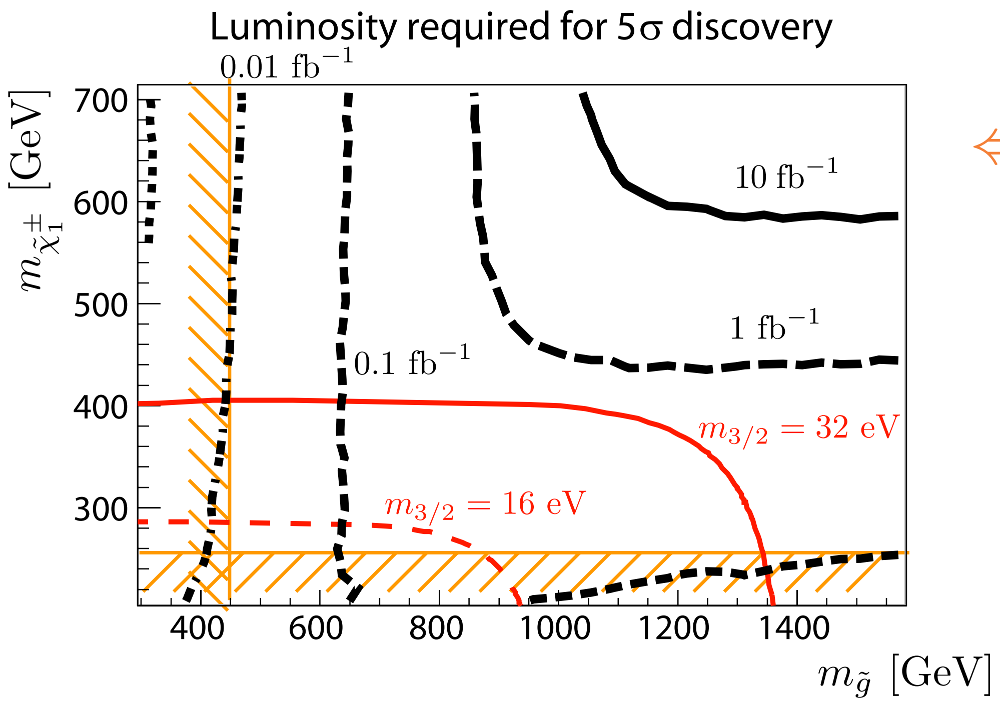
[Olive]

- Significant coverage of the bulk region for neutralino dark matter (in the CMSSM)
- The present Higgs mass bound is quite severe
- Phenomenology strongly depends on $\tan\beta$

SUSY model: Low-scale gauge mediation

$\Rightarrow$ The lightest neutralino decays into photon and gravitino

$\Rightarrow$ Energetic photons are emitted in the SUSY event



$\Leftarrow$ Two isolated energetic γ

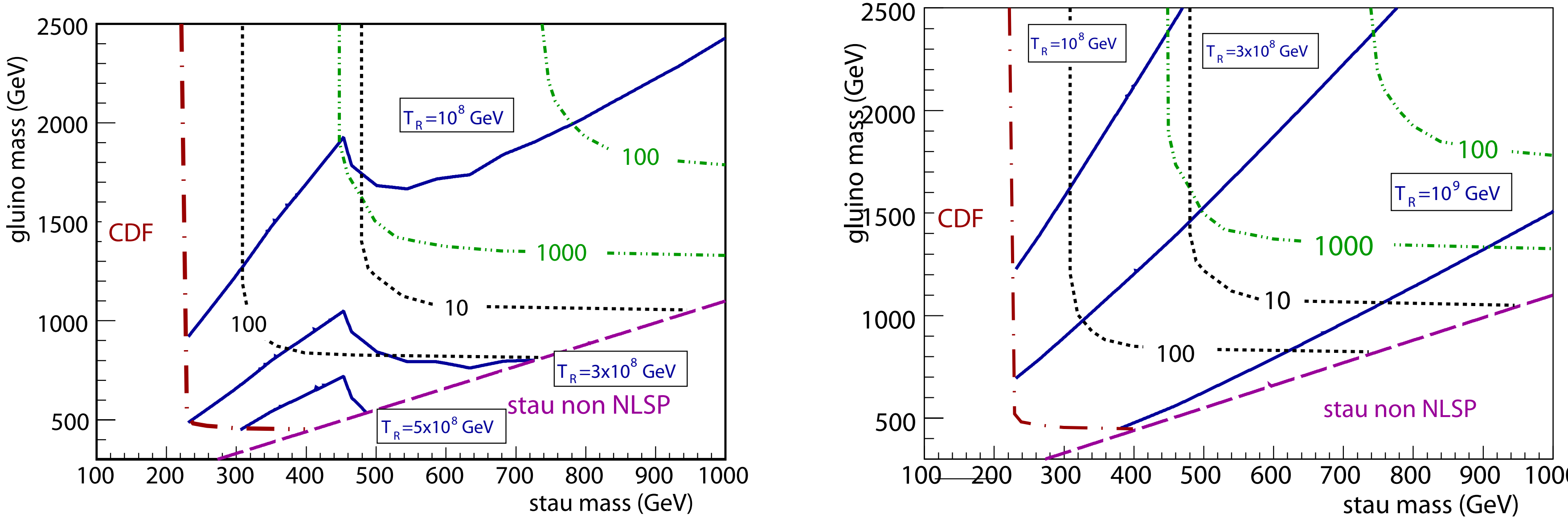
[Sato & Shirai]

$\Rightarrow$ The early LHC can confirm/exclude some class of low-energy gauge mediation model

SUSY model: gauge mediation with long-lived $\tilde{\tau}$

$\Rightarrow$ $\tilde{\tau}$ may be the lightest MSSM particle in GMSB

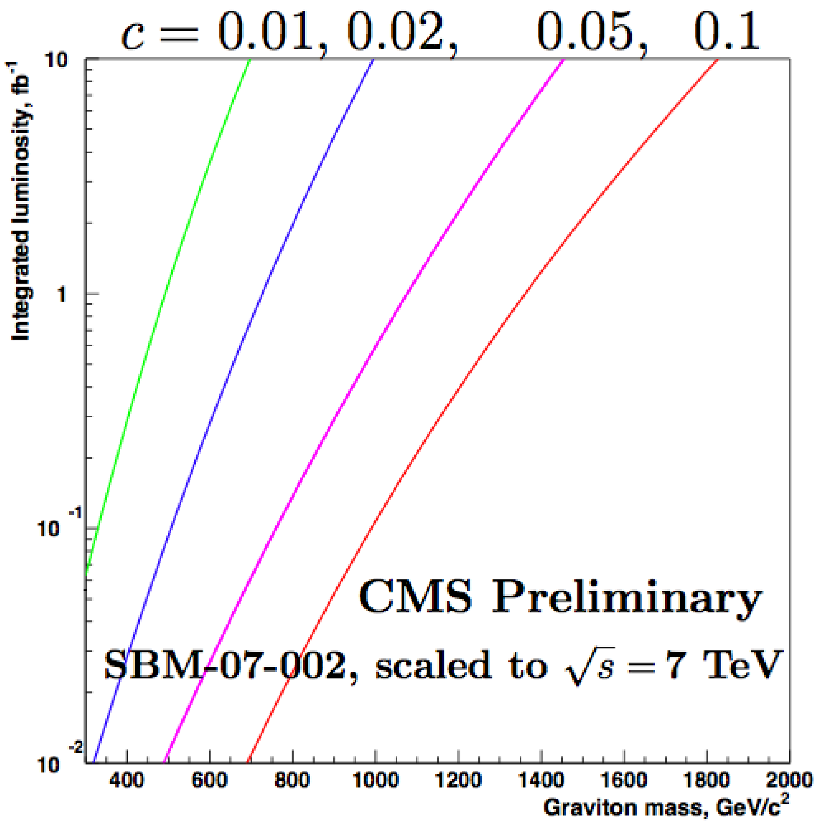
$\Rightarrow$ Long-lived charged tracks are expected in SUSY events

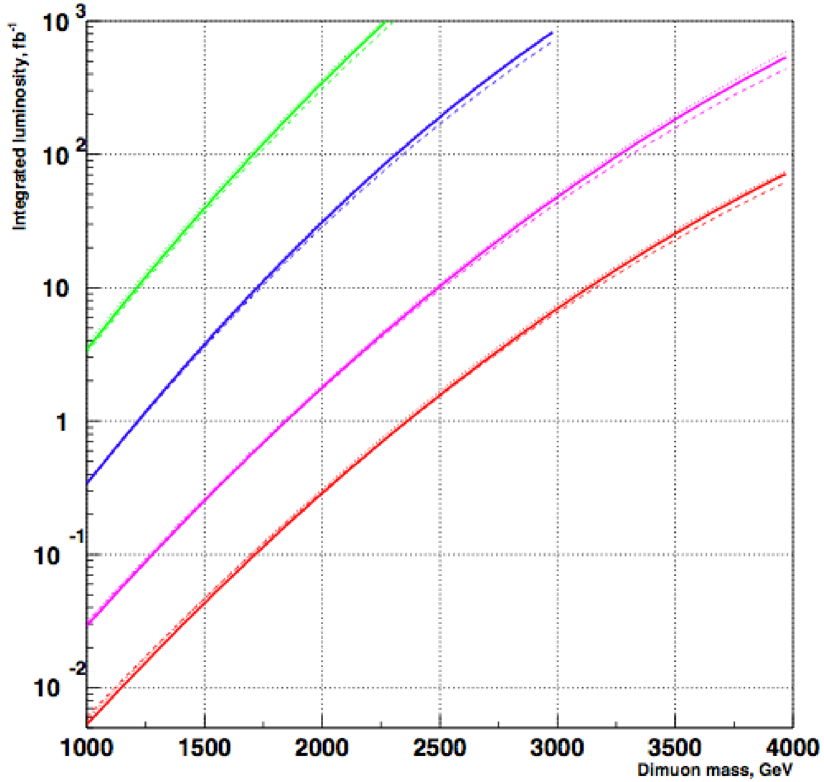


[Endo, Hamaguchi & Nakaji]

$\Rightarrow$ Constraint on the reheating temperature after inflation (if combined with BBN constraints)

Discovery reach: RS-graviton (in di-muon channel)



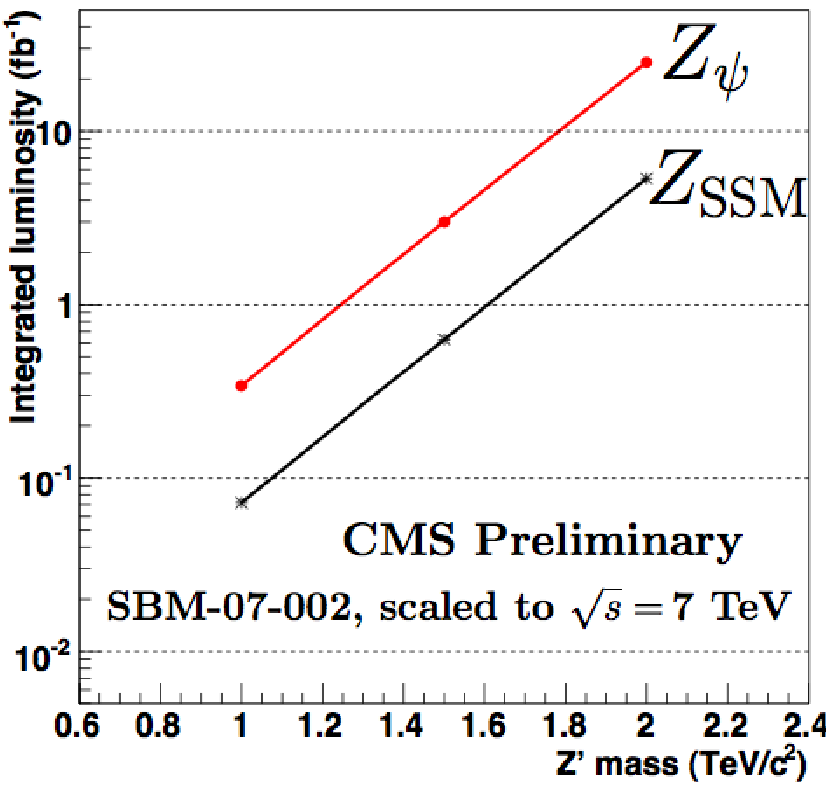


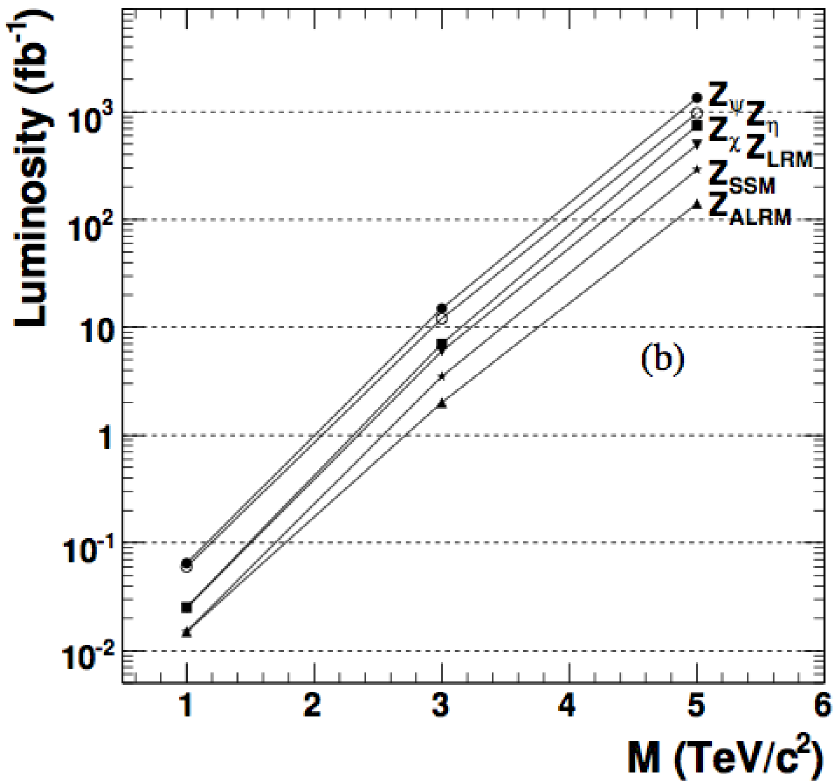
[CMS note]

$\Rightarrow$ Discovery reach: $m_G \lesssim 0.4 - 1.2$ TeV with 7 TeV & 1 fb^{-1}

$h^{(1)}_{\alpha\beta}$-μ^+-μ^- coupling $\propto c = k/M_{\rm Pl}$

Discovery reach: Z'





[CMS note]

$\Rightarrow$ Discovery reach: $m_{Z'} \lesssim 1.2 - 1.6$ TeV with 7 TeV & 1 fb^{-1}

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LHC is working well

$\Rightarrow$ SM particles are being re-discovered

$\Rightarrow$ We should appreciate all the efforts of LHC people

We may see a signal of new physics beyond the SM

$\Rightarrow$ Early LHC run $\neq$ "engineering run" or "warm-up run"

$\Rightarrow$ Some class of models are excluded if the early LHC does not see anything

Many models are not covered by the early LHC, though

$\Rightarrow$ Run with $\sqrt{s} = 14$ TeV is awaited